

National Aeronautics and Space Administration



Extreme Temperature Performance of Automotive-Grade Small Signal Bipolar Junction Transistors

**NASA Electronic Parts and Packaging (NEPP) Program
Office of Safety and Mission Assurance**

Kristen Boomer
NASA Glenn Research Center
Cleveland, Ohio

Benny Damron
Jacobs Technology/ESSSA Group
Huntsville, Alabama

Josh Gray
NSWC Crane Division
Crane, Indiana

Ahmad Hammoud
Vantage Partners, LLC
Cleveland, Ohio

Extreme Temperature Performance of Automotive-Grade Small Signal Bipolar Junction Transistors


Scope

Electronics designed for space exploration missions must operate efficiently and reliably under extreme temperature conditions. For example, lunar outposts, Mars rovers and landers, the James Webb Space Telescope, a Europa orbiter, and deep space probes represent examples of missions where extreme temperatures and thermal cycling are encountered. Switching transistors, small signal as well as power-level devices, are widely used in electronic controllers, data instrumentation, and power management and distribution systems. Little is known, however, about their performance in extreme temperature environments beyond their specified operating range, in particular under cryogenic conditions. This report summarizes preliminary results obtained on the evaluation of commercial-off-the-shelf (COTS) automotive-grade NPN small signal transistors over a wide temperature range and thermal cycling. The investigations were carried out to establish a baseline on functionality of these transistors and to determine suitability for use outside their recommended temperature limits.

Test Procedure

The COTS parts investigated in this work comprised of Diodes Incorporated surface mount, 40V NPN small signal MMDT3904 transistors. These ultra-small devices are ideal for medium power amplification and switching, and are qualified to AEC-Q101 (Automotive Electronics Council) standards for high reliability [1]. Table I shows some of the transistor manufacturer's specifications. Two batches of these transistors, for a total of 8, were investigated in this work. One batch consisted of 4 pristine units while the other comprised of 4 transistors that were subjected to an earlier life-testing at the Naval Surface Warfare Center in Crane, Indiana [2]. The transistors were examined in terms of their switching I/V characteristics using a Sony/Tektronix 370A programmable curve tracer. Other properties investigated included DC current gain (h_{FE}), small signal current gain (h_{fe}), collector-emitter breakdown voltage (BV_{CEO}), and collector-base breakdown voltage (BV_{CBO}).

Table I. Manufacturer's specifications of MMDT3904 transistor [1].

Parameter	Symbol	
Collector-Base Breakdown Voltage (V), Minimum	BV_{CBO}	60
Collector-Emitter Breakdown Voltage (V), Minimum	BV_{CEO}	40
DC Current Gain	h_{FE}	30 - 300
Small Signal Current Gain	h_{fe}	100 - 400
Collector Current (mA), Absolute	I_C	200
Power Dissipation (mW)	P_D	200
Operating Temperature (°C)	T_J	-55 to +150
Package		Plastic SOT363
Part Code		NSA100SHPD

These evaluations were performed at specific test temperatures over a wide temperature range between -192 °C and +150 °C. A temperature rate of change of 10 °C per minute was used, and a soak time of at 15 minutes was allowed at every test temperature. Cold-restart capability of the transistors was also investigated. The effects of thermal cycling on the operation of these transistors were then followed by subjecting the eight devices to a total of 1000 cycles between -192 °C and +150 °C at a temperature rate of 20 °C/minute. Following the thermal cycling, measurements of the transistors properties were retaken at various test temperatures. Figure 1 shows a transistor package on a 6 pin SIP-adaptor/surfboard.

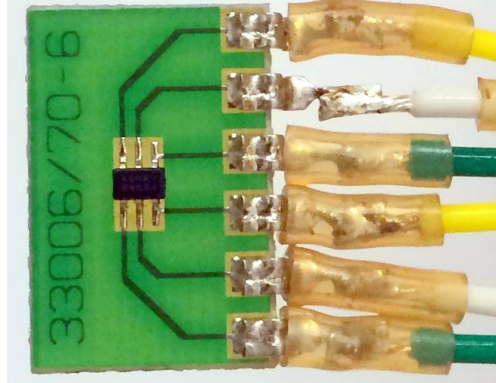


Figure 1. Transistor package mounted on a test board.

Test Results

As indicated earlier, a total of 8 transistors were investigated in this work where half of them were pristine units and the others were subjected to life-testing. The results, though, revealed that all transistors, irrespective of batch lot, displayed similar trend in their behavior with temperature. Therefore, data pertaining to only one transistor are presented.

Temperature Effects

Figure 2 shows the switching characteristics of the MMDT3904 NPN transistor at various test temperatures. These output characteristics are defined as collector current (I_C) versus collector-to-emitter (V_{CE}) voltage family curves at various base currents (I_B). As the test temperature was decreased below room temperature, the base current had to undergo a gradual, but slight, increase to maintain the collector current at a predetermined value for a given V_{CE} . This required incremental increase in the base current tends to be significant at temperature of about -100 °C, becoming more exacerbated as temperature was reduced further, as shown in Figure 2. Under high temperature exposure, however, not only did such behavior not occur but also the transistor displayed slight improvement in its output characteristics. As evident in Figure 2, the decrease in test temperature has resulted in a downward shift of the family curves, at any given operating bias point. In addition, larger step size in the base biasing current was warranted to maintain a given collector current, indicative of the decrease in the DC as well as small signal current gains of the transistor as temperature was decreased. This effect of temperature on the transistor's DC and small signal gains is shown in Figures 3 and 4, respectively.

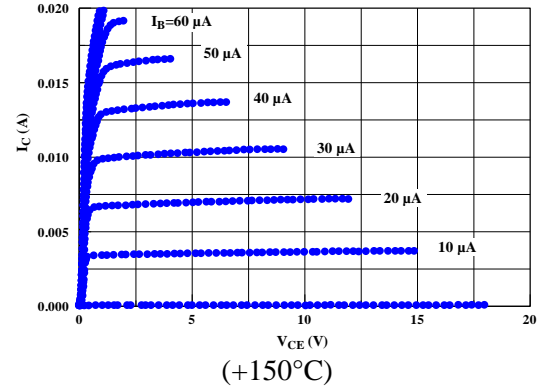
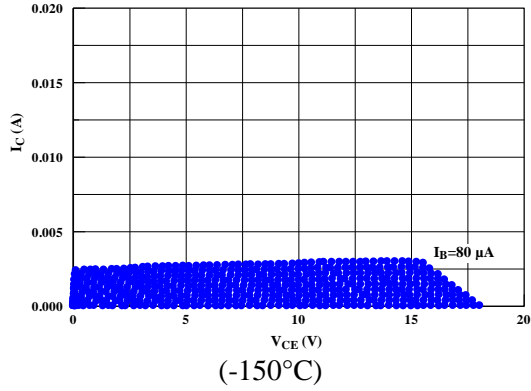
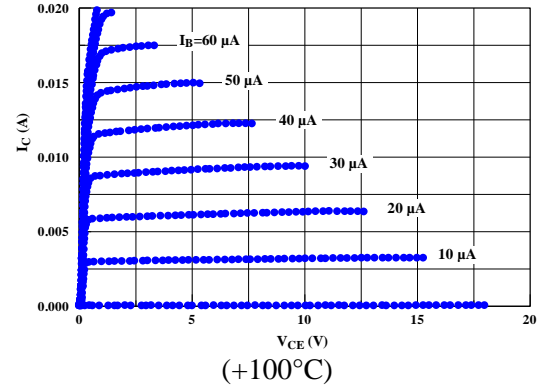
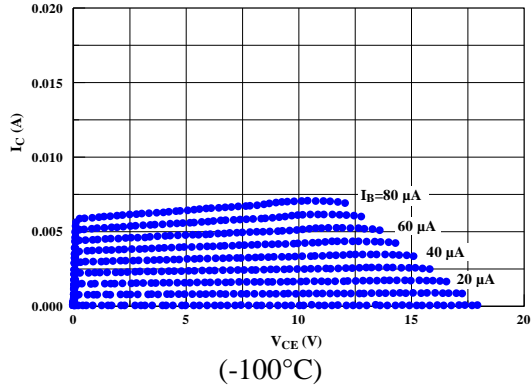
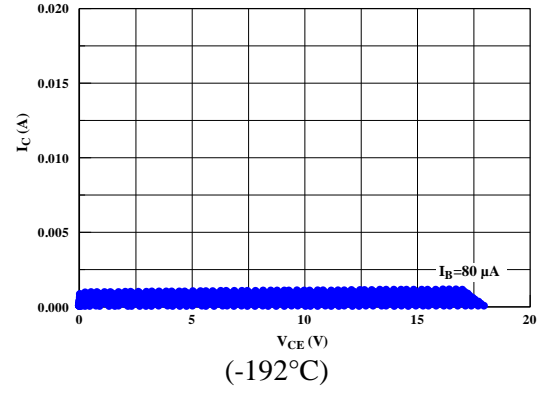
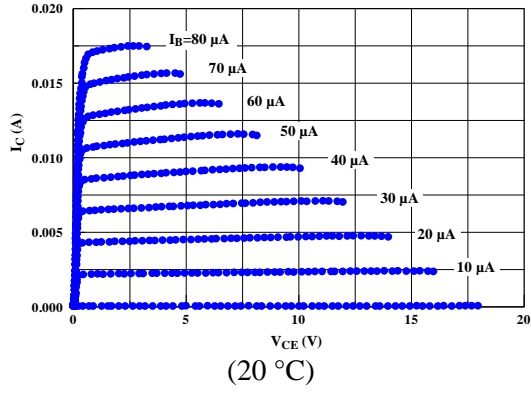


Figure 2. I/V characteristics of MMDT3904 transistor at various test temperatures.

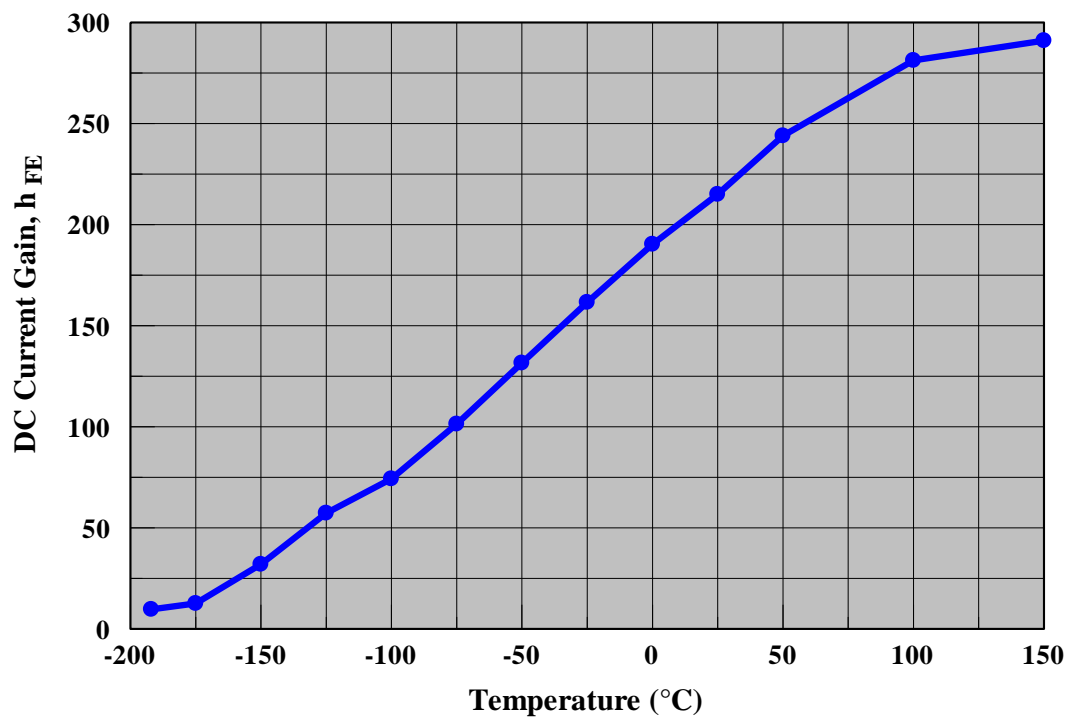


Figure 3. Transistor DC current gain versus temperature.

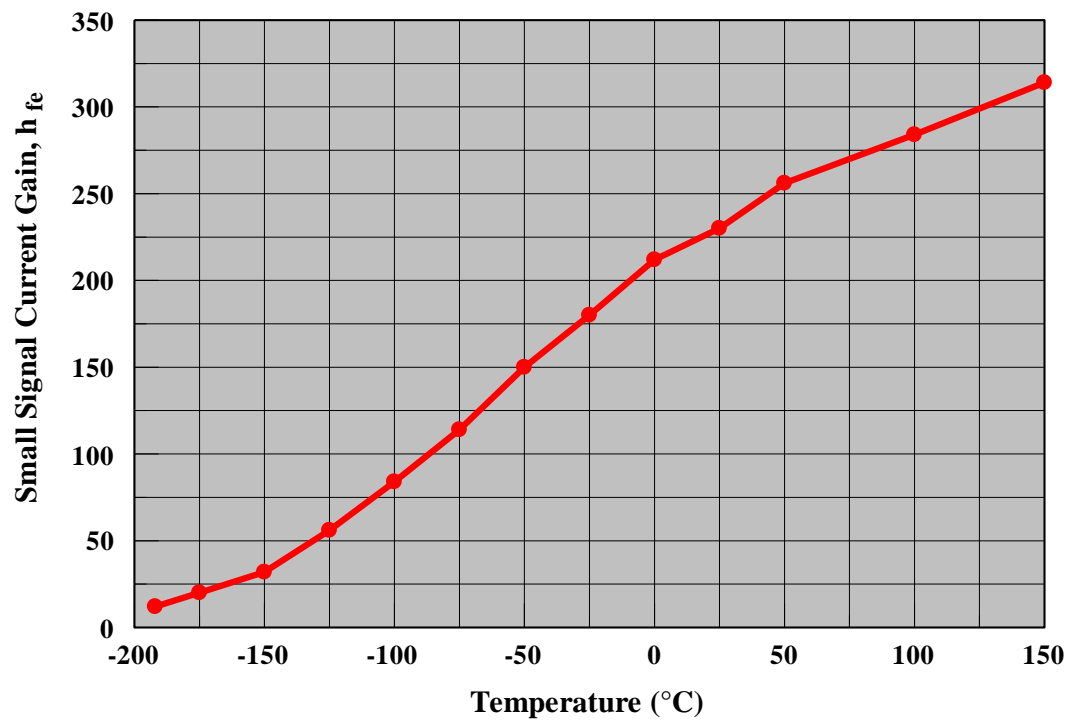


Figure 4. Transistor small signal current gain versus temperature.

The collector-emitter breakdown voltage (BV_{CEO}) of the MMDT3904 transistor as a function of test temperatures is shown in Figure 5. It can be clearly seen that the collector-emitter breakdown voltage didn't undergo any significant change with variation in temperature throughout the test range of $-192\text{ }^{\circ}\text{C}$ to $+150\text{ }^{\circ}\text{C}$. Such was not the case, however, to the collector-base breakdown voltage (BV_{CBO}) property of this BJT transistor. This dependence on temperature, albeit modest, is depicted in Figure 6 where the value of the collector-base breakdown voltage slightly decreased, almost linearly, as the test temperature was lowered below room temperature and exhibited gradual increase in the high temperature region.

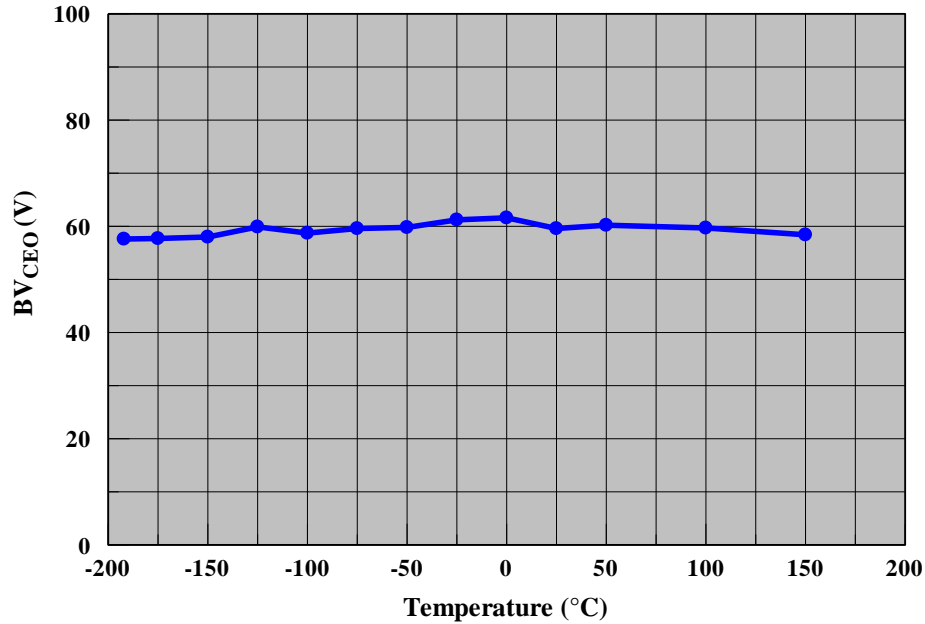


Figure 5. Collector-emitter breakdown voltage as a function of temperature.

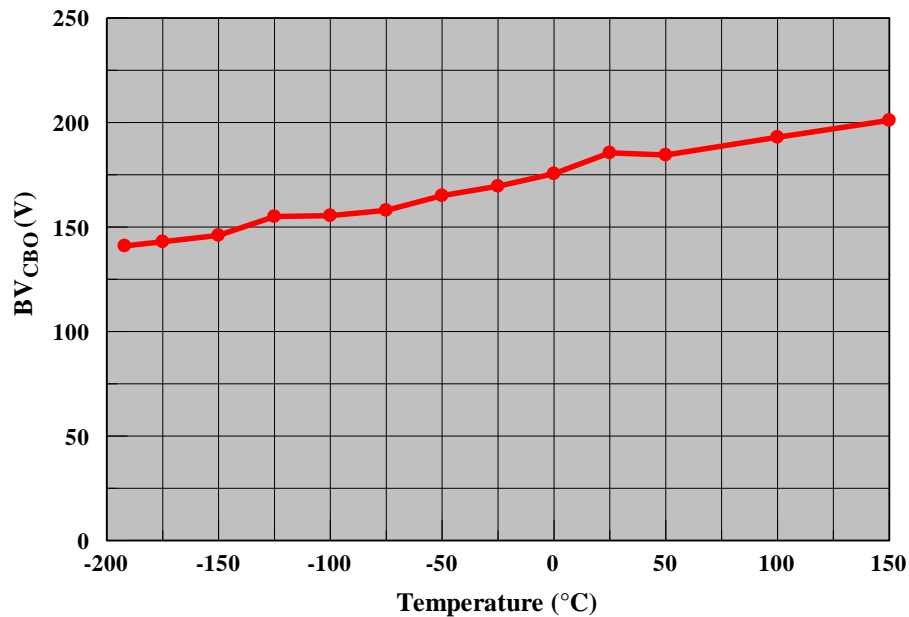


Figure 6. Collector-base breakdown voltage as a function of temperature.

Cold-Restart

Cold-restart capability of the MMDT3904 transistors was investigated by allowing the devices to soak at $-192\text{ }^{\circ}\text{C}$ for 20 minutes without electrical bias. Power was then applied to the device under test, and measurements were taken on the forward V/I characteristics. All transistors were able to switch on, but with diminished gain, at the cryogenic temperature of $-192\text{ }^{\circ}\text{C}$.

Effects of Thermal Cycling

The effects of thermal cycling on the operation of the eight transistors were investigated by subjecting them to a total of 1000 cycles between $-192\text{ }^{\circ}\text{C}$ and $+150\text{ }^{\circ}\text{C}$ at a temperature rate of $20\text{ }^{\circ}\text{C}/\text{minute}$. Post-cycling V/I characteristics of the transistors were then recorded at various test temperature. Comparison of the post-cycling data along to those obtained prior to cycling revealed that none of the devices under any significant change due to this cycling activity. For illustration purposes, the I/V characteristics for one of these transistors taken at the test temperatures of $+20$, -100 , -192 , and $+150\text{ }^{\circ}\text{C}$ are shown, for both pre- and post-cycling conditions, in Figures 7 and 8. This thermal cycling activity also appeared to have no effect on the structural integrity of these transistors as none underwent any structural deterioration or packaging damage.

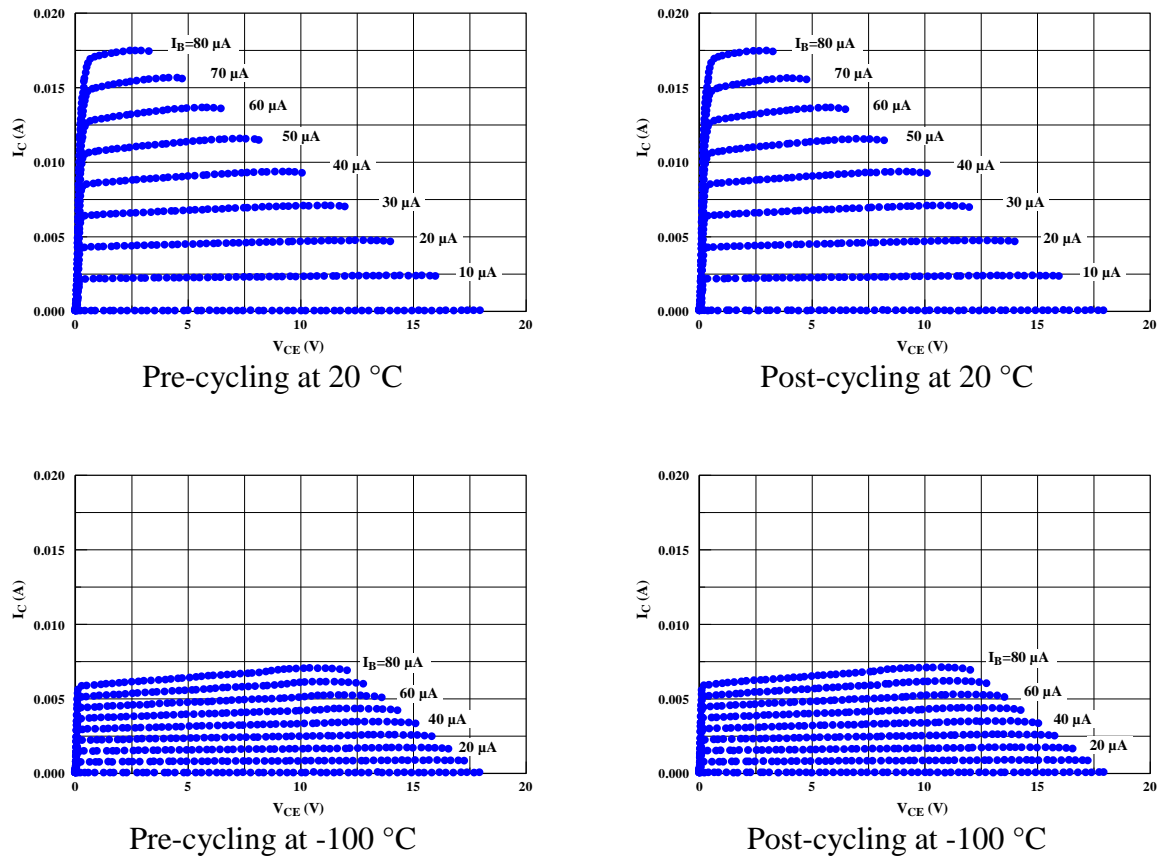
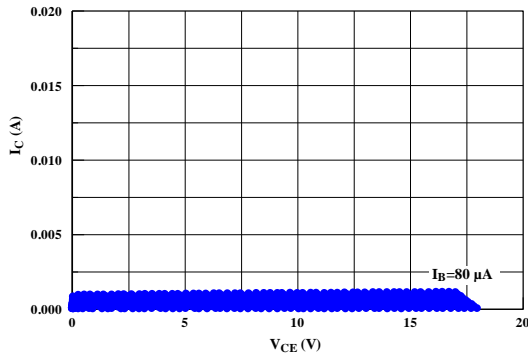
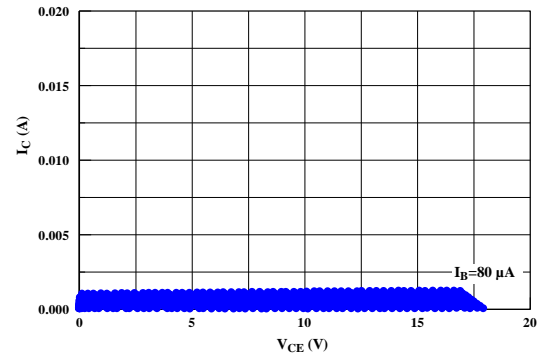


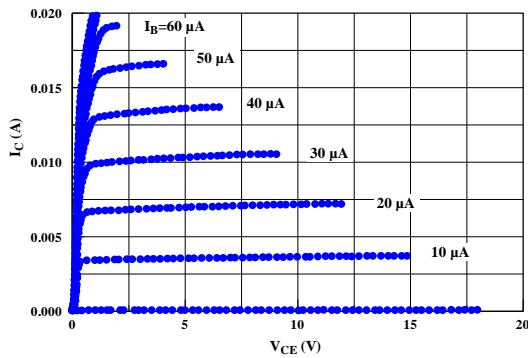
Figure 7. Pre- and post-cycling I/V curves at selected test temperatures.



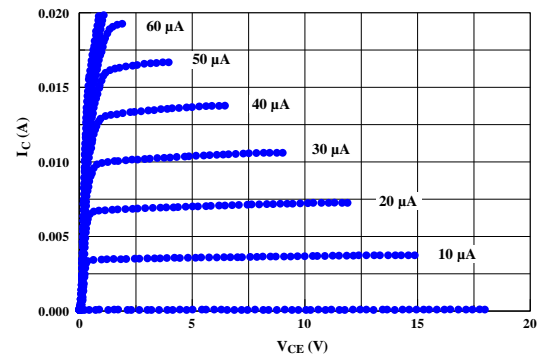
Pre-cycling at -192 °C



Post-cycling at -192 °C



Pre-cycling at +150 °C



Post-cycling at +150 °C

Figure 8. Pre- and post-cycling I/V curves at selected test temperatures.

Conclusions

Two batches of automotive-grade, 40V NPN small signal transistors, Diodes Incorporated MMDT3904, were evaluated for operation under extreme temperatures extending beyond their specified low temperature range. While one batch consisted of 4 pristine units, the other comprised of 4 transistors that were previously subjected to life-testing. Performance of all transistors were examined in terms of their switching I/V characteristics, DC current and small signal current gains, and collector-emitter and collector-base breakdown voltages over the wide temperature range of -192 °C to +150 °C. Cold-restart capability of the transistors as well as the effects of thermal cycling on their operation were also investigated. All transistors, from either batch, displayed similar behavior in their characteristics with temperature. The transistors began to exhibit slight to significant variation in some of the investigated properties at temperature of about -100 °C; with the changes becoming more exacerbate as temperature was reduced further. While the collector-emitter breakdown voltage didn't undergo any significant change with variation in temperature throughout the test range of -192 °C to +150 °C, the collector-base breakdown voltage underwent mild reduction in its value as the test temperature was lowered below room temperature. The reduction in the current gain of the transistor was the most dominant change occurring at lower temperature; almost diminishing completely

at the cryogenic temperature of -192 °C. Subjecting the transistors to thermal cycling produced no effect on their characteristics, and all devices were able to cold-restart at -192 °C. The transistor's plastic packaging was also not affected by either the extreme temperature exposure or the thermal cycling. These preliminary results indicate that these surface-mount transistors may be used at a temperatures slightly below than their low temperature specified limit, depending on circuit requirement and device functionality. Further testing under combined biased-condition and thermal cycling is needed to fully establish the reliability of these devices and to determine their suitability for extended use in extreme temperature environments.

References

- [1]. Diodes Incorporated, "MMDT3904 40V Dual NPN Small Signal Transistor in SOT363" Document Number: DS30088 Rev.18-2, April 2016.
<https://www.diodes.com/assets/Datasheets/ds30088.pdf>
- [2]. Results are being documented in a test report.

Acknowledgements

This work was performed in support of the NASA Electronic Parts and Packaging (NEPP) Program. Guidance and funding provided by the Program's co-managers Kenneth LaBel and Michael Sampson are greatly appreciated. Part of this effort was done at the NASA Glenn Research Center under GESS-3 Contract # NNC12BA01B.